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Rural household energy consumption and its impacts on eco-environment in Tibet: Taking Taktse county as an example

Gang Liu[a,b,*], Mario Lucas[c], Lei Shen[a]

[a]*Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Science, Beijing 100101, PR China*
[b]*Graduate University of Chinese Academy of Science, Beijing 100049, PR China*
[c]*RWTH Aachen University, Aachen 52070, Germany*

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Abstract

Rural energy consumption causes tremendous damage to eco-environment and leads to aberration from a socio-economic point of view in many developing countries. Due to its unique physical features, there is a high potential of renewable energies in Tibet and traditional biomass energies such as cattle dung, firewood and crop residues play very important roles in local household energy usage. This special consumption structure do harm not only to eco-environment but to rural residents themselves as well. Basing on the field study and household questionnaires in June 2006 in Taktse, the article analyzed the rural household energy supply and consumption structure, and its impacts on eco-environment, health and social aspects of 2005 in this case study county. Results show that traditional biomass energy takes up to almost 70%, which leads to a series of serious eco-environment problems such as deforestation, soil erosion, grassland degradation, desertification, and some other problems such as human beings diseases and loss of time for education and recreation. Besides natural backgrounds, cultural tradition, population growth, economy reason and policy guidance are other main driving forces of the input–output flow of energy–environment relationship

*Corresponding author. Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Science, Beijing 100101, PR China. Tel.: +86 10 13810450283; fax: +86 10 64889005.
E-mail addresses: liug.04s@igsnrr.ac.cn, geoliugang@gmail.com (G. Liu).

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in rural Tibet. At last, a multilevel policy suggestion of making less use of traditional biomass and invest more resources in solar energy and biogas are put forward.

Keywords: Rural household energy consumption; Eco-environmental impact; Health impact; Biomass energy; Taktse; Tibet Autonomous Region (TAR)

Contents

0. Introduction 1891
1. Natural and socio-economic backgrounds of study area 1892
2. Methodology. 1893
3. Rural household energy supply and consumption structure in Taktse. 1895
   3.1. Energy potential and supply structure. 1895
      3.1.1. Biomass energy. 1895
      3.1.2. Solar energy. 1896
      3.1.3. Electricity 1896
      3.1.4. Fossil fuel 1897
   3.2. Energy consumption structure 1898
4. Eco-environmental impacts of rural energy consumption in Taktse 1899
   4.1. Eco-environment degradation. 1899
   4.2. Health impact and social impact 1902
   4.3. Driving forces. 1903
5. Discussions and suggestions 1905
   5.1. Improve stove efficiency 1905
   5.2. Widespread use of solar energy and LPG 1905
   5.3. Great potential of household biogas plant. 1906
   5.4. Adjustment of agriculture structure 1906
   Acknowledgments 1907
   References 1907

0. Introduction

In many developing countries, rural energy consumption causes tremendous damage to eco-environment and leads to aberration from a socio-economic point of view [1,2]. On one hand the traditional use of biomass very often is the only way to ensure cooking, heating and lighting, on the other hand it is a direct intervention into eco- and socio-economic environment and their open loop [3–7]. In general, according to different or similar natural conditions, socio-economic backgrounds, political purposes and technical support, similar domestic energy use patterns have been emerged in the developing countries all over the world such as India [8], Sri Lanka [9], Bangladesh [10], Sudan [11], Nigeria [12] and China [13], too.

The Tibet Autonomous Region (TAR) forms the main part of the Tibet Plateau, which is the highest Plateau of the world with an average altitude over 4000 m above sea level. Unique physical features resulting from this location hold both risks and chances with a view to land use. The outstanding natural conditions, which distinctively differ from

location to location and in general offers a high potential of renewable energies such as solar, wind, hydro and geothermal power, the ubiquitous natural lack of fossil fuels such as coal, oil and gas, the economic structure in which the primary sector is still dominating as well as the social structure of population have been developing special patterns of energy consumptions and technologies. Even though the technical options of the usage of clean renewable energy has been improved, and a permanent growth of the secondary sector can be seen after the energetic support by the central government since the 1950s, a huge majority of the Tibetan population who lives in rural regions still consumes biomass energy in its most traditional terms of cattle dong, firewood and crop residue.

At the same time, a wide range of different feedbacks on the eco- and socio-economic environment resulting from the use of biomass can be identified leading to land degradation, health impairments and less opportunities of education. Comparing to other regions of China, those environmental vitiations referring on energy use have not yet entered the level of irreversibility, but according to a sustainable development and due to Tibet's environmental fragility it is necessary to understand more about the effects of biomass use inside rural regions of TAR. On the basis of the new consolidated findings, adequate suggestions finally can be given.

In this paper, after introduction of the natural and socio-economic facets of the case study county and our methodology in detail in following section first, we try to identify main energy sources inside local households based on our investigation in June 2006, illustrate its main impacts on eco- and socio-economic environment and the determining parameters, and finally discuss the use of Best Practical Technologies (BPTs) in the county of Taktse.

1. Natural and socio-economic backgrounds of study area

Taktse, which lies in the central area of TAR and 25 km east to Lhasa city, is located in the lower reaches of the Kyi Chu (Lhasa river), the branch of the Yarlung Zangbo river. The average altitude is 4500 m. Taktse is surrounded by mountains both in its northern and in its southern parts, while there is 3–4 km wide table-land along the Lhasa river valley in the central belt area. Taktse belongs to the plateau semiarid and temperate zones, featuring abundant solar energy and rainfall. Long-term observations by the Lhasa state key ecological station, which is just situated in Taktse, shows that the annual average sunshine duration is about 3007.7 h and the annual average rainfall is 444.8 mm. The temperature is moderate with an annual mean value of 6.7 °C ranging from −15.8 to 26 °C. The annual average relative humidity is above 50% and the wet and dry seasons are very distinct with the rain season lasting from June to September.

The total area of Taktse is 1373.25 km^2 consisting of 6 towns, 21 administration villages and 128 natural villages. Due to the special geographical environment and historical reasons, the population is very small and grows slowly. The average annual increasing rate was 1.50%, 1.94% and 0.36% of the different periods 1960–1978, 1978–1990 and 1990–2005, respectively. In 2005, the population gets to 25,903 but the density was also only 19 person km^{-2}. Among the total population, 93.84% are rural farmers or herdsmen.

Agriculture and animal husbandry play the most important role in Taktse county. Statistical data shows that the GDP was 232 million yuan and the total rural income was 116.9 million yuan in 2005. The primary sector, secondary sector and tertiary sector were 93.87, 67.10 and 16.32 million yuan, respectively, in Taktse's total rural income. Although

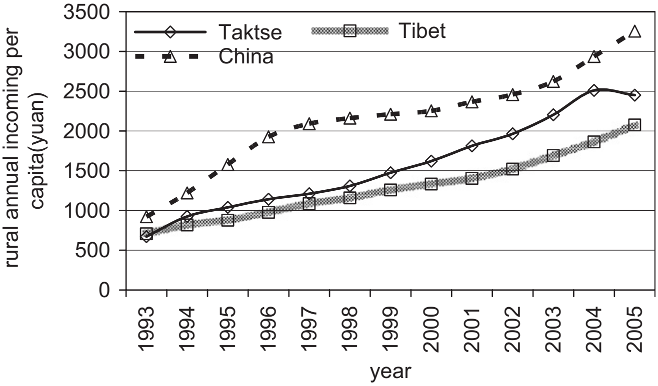


Fig. 1. Rural annual income per capita of Taktse, TAR and China (1993–2005).

Taktse is an undeveloped county compared to the average level of China or the inland areas, it also belongs to one of the most developed counties in TAR because of its location close to Lhasa and good conditions for agriculture. Its GDP per capita in 2005 reached up to 8956 yuan (or 1109 dollars) and ranked the 19th among all the 73 counties and cities in TAR. We also can see this situation from Fig. 1, which shows the rural annual income per capita of Tastse, TAR and China.

2. Methodology

In order to gather direct information on the energy use patterns of rural households as well as resulting environmental changes in Taktse county, we have compiled a questionnaire, which consists of four main data groups as follows:

- *Basic information*: In this part we gathered some general information on the human beings such as their living circumstances, including the income situation, consumption and expenditures as well as job related data like crop production and the size of livestock.
- *Energy survey*: This section contains energy related data in the range of energy supply, energy demand and efficiency. Thereby, we mainly focused on the use of biomass as well as its quantitative (e.g. daily burned or collected amount of biomass) and qualitative (e.g. sources of energy supply) aspects.
- *Impacts on environment*: Under this point we tried to get information about the impacts of energy use on the eco- and socio-economic environment. Grassland degradation on the eco-environmental site and diseases caused by air pollution formed the center of our interest in this part.
- *Key technologies and demands*: The main purpose of this category is to figure out what energy technology the people consider to be the best for themselves with regard to their demands, financial situation and environmental protection.

During a field study from the 7th till the 21st of June 2006 we have selected 61 representative households including 35 agricultural and 25 pastoral households inside four

towns namely Tangga, Zhangduo, Tajie and Bangdui, according to Taktse as a half-farming and half-grazing zone (Table 1). In total, the questionnaire contains about 100 single questions and we took part in the interview to make sure the people get the right sense of our questions and do not give wrong or dissatisfying answers due to misunderstandings. In addition to this rather comprehensive questionnaire, we have designed a quite simple questionnaire that contains some very general questions about energy use on one page and has been distributed to commercial institutions of Taktse like restaurants, stores and gas stations.

Facing some difficulties in carrying out our survey such as transportation due to badly constructed routes, distribution of the questionnaires and language we yet got useful results that confirm our assumptions of usage of biomass and its impacts on eco- and socio-economic environment in Taktse quite well as well as we have found typical patterns of household energy use.

Furthermore, we will estimate the amount of crop residues, dung and firewood for Taktse by using a rather simple calculation to identify the total biomass potential and a further one to see its different use and efficiency for energy consumption [14]. Due to not being included in the governmental statistics yearbook, crop residue is usually estimated by the output of crops. The formula goes as formula (1), then the estimation of residue-to-product ratio (RPR) is the key step of crop residue's calculation. RPR is an empirical constant, which can be gained by field observation and experimentation. There will be a little difference considering regions and types. In this paper, we confirm RPR of different types of crops by the result of existed research and our experiment with the help of bureau of agriculture in Taktse. The amount of dung and stale is concerned with the type, breed, gender and feeding period of animal. So, it can be estimate by the production each day and the feeding period. The formula goes as formula (2):

$$\mathrm{CR} = \sum_{i=1}^{n} \mathrm{Qc}_i \, r_i. \quad (1)$$

Table 1
Basic situation of surveying towns in Taktse

Towns	Tangga	Zhangduo	Tajie	Bangdui
Altitude (m)	3755	3738	3730	3706
Area (km^2)	247.3	165.0	170.9	181.8
Distance to the county town (km)	42	23	14	5
Total households	927	766	628	771
Total population	4917	3925	2950	3542
Number of administration villages	3	4	3	4
Number of natural villages	25	23	16	18
Pure pastoral natural villages	3	4	4	2
Un-electrified natural villages	3	7	3	2
Selected administration villages	3	2	2	2
Selected households	14	15	16	16
Selected population	65	61	94	92

Table 2
Main energy supply sources of different usage type in rural household in Taktse

Usage	Main sources		Availability	
	Agriculture area	Pasture area	Agriculture area	Pasture area
Cooking	LPG, cattle dung, firewood	Cattle dung, firewood	Abundant	Abundant
Boiling water	Solar stove, cattle dung	Solar stove, cattle dung	Abundant	Abundant
Lighting	Electricity	PV	Abundant	Lacking
Heating	Electricity, coal	None	Lacking	Extremely lacking
Household appliances	Electricity	None	Abundant	Lacking
Motive power	Diesel oil and gasoline	Diesel oil and gasoline	Lacking	Extremely lacking

where CR stands for the amount of crop residues, Qc_i is the production of crop i, r_i is the RPR of crop i:

$$D = \sum_{i=1}^{n} \mathrm{Qd}_i\, d_i m_i = \sum_{i=1}^{n} \mathrm{Qd}_i\, M_i, \tag{2}$$

where D stands for the amount of dung, Qd_i is the amount of livestock i, d_i is the dung production each day of livestock i, m_i is the feeding period of livestock i, and M_i is the total production in the feeding period of livestock i.

Information on domestic energy consumption and possible eco-environmental impacts can be collected through these questionnaires and interviews in selected households. Via satellite data we try to point out the LUCC during the last years and try to find relevant changes being part of energy consumption, especially for deforestation. Using GIS software we are able to prepare data and present them in a clear way.

3. Rural household energy supply and consumption structure in Taktse

3.1. Energy potential and supply structure

Like in the rest of TAR, Taktse has abundant renewable energy resources and its rural household sector depends largely on traditional sources of energy. The main energy supply sources in Taktse include solar energy such as solar stove and photo voltaic (PV) equipment, biomass energy such as cattle dung, crop residue and firewood, liquid petroleum gas (LPG) and electricity. It can be imagined that there were some differences of main sources and availabilities between agriculture areas and pastoral areas (Table 2).

3.1.1. Biomass energy

Biomass is the most important energy in TAR and takes up almost 70% of the whole household energy as result of its special natural situation and socio-economic background. In Taktse, agriculture, animal husbandry and forestry also provide with plenty of biomass energy, such as crop residues, cattle dung and firewood.

In TAR, highland barley, wheat, rape, potato and beans are these common crops. Crop residues are mainly used to feed livestock and small amount of them are also burned directly for cooking and heating. Dung of livestock is the most traditional and important

Table 3
Biomass energy potential appraisal in Taktse

	Total amount (t)	RPR/M_i (kg)	Biomass amount (t)	Standard conversion coefficient	Standard energy (tce)	Total potential (10^4 tce)
Highland barley	5185.48	1.1	5704.03	0.500	2852.01	3.135
Wheat	18,079.96	1.1	19,887.96	0.500	9943.98	
Bean	241.39	1.7	410.36	0.543	222.83	
Potato	5333.50	1.0	5333.50	0.486	2592.08	
Rapeseed	2116.50	3.0	6349.50	0.529	3358.89	
Cattle	47,125	1095	51,601.88	0.471	24,304.48	1.897
Horse, mule and donkey	2263	900	2036.70	0.529	1077.41	
Sheep and goat	70,261	92	6464.01	0.529	3419.46	
Pig	6059	1050	6361.95	0.429	2729.28	

source of energy in TAR. People use cattle dung to cook and warm for thousands of years in Tibet Plateau.

Firewood used to be a traditional source of energy in Taktse. But the large and unsustainable consumption and deforestation in 1970s and 1980s led to a sharp decline of the forest area. Measures were taken to protect the forest from 1998 on, even shrubs and thorns along the river valley are forbidden to be cut down. Generally speaking, people only use the special firewood forest and branches and leaves from natural forest to light fire now. In 2005, the forest area is 10,545 ha and the percentage of forest cover is 7.7%.

Then we can get the biomass energy potential from formulas (1) and (2), the result is shown in Table 3.

3.1.2. Solar energy

Taktse is blessed with good sunshine. The total solar radiation amount is 7000–8000 MJ m^{-2} year^{-1}, and the photosynthetically available radiation (PAR) accounts for about 43%. The sunshine quality is so good that there are 4.44 mol quanta in every joule PAR. The total sunshine duration of Taktse is about 3007.7 h year^{-1} and the actual value accounts for 68% in which it is 666.6 h year^{-1} and accounts for 22.3% in spring and the ratio is 27.5%, 25.6% and 24.7% in summer, autumn and winter, respectively.

Due to the great potential of solar energy and lack of commercial energy, the government strives hard to popularize solar energy equipment in rural households, such as solar stoves for cooking and PV system for lighting. Solar stoves are widely used for boiling water and usually five to eight boilers can be boiled every day. PV equipment can supply a 25–50 W light for 4–6 h per day, which means a lot in the un-electrified households in the mountain pastoral area. A batch of solar stoves and PV equipments were donated to the rural households by local government in 2006, when TAR celebrated its 40th anniversary of founding. Our survey showed that there are even more than one solar stove per household in Taktse (Table 4).

3.1.3. Electricity

There are four electricity grid in TAR, namely central grid, Chamdo(eastern) grid, Shiquanhe(western) grid and Nyingtri grid. Taktse gets its power supply from the central

Table 4
Number of solar equipment in the surveying four towns in Taktse

Towns	Households	Solar stove			PV		
		Total	Average	Donated	Total	Average	Donated
Tangga	927	1500	1.62	927	80	0.09	61
Zhangduo	766	1000	1.31	755	74	0.10	54
Tajie	628	700	1.11	628	35	0.06	30
Bangdui	771	950	1.23	750	40	0.05	25

Table 5
Electricity load (in MW) forecasting in Taktse

Towns	2005	2010	2015	2020
Deqing	1.7	3.7	5.9	8.3
Tajie	0.3	0.5	0.7	1
Zhangduo	0.2	0.4	0.6	0.9
Tangga	0.1	0.3	0.5	0.8
Xue	0.1	0.3	0.5	0.8
Bangdui	0.2	0.4	0.6	0.9
Total	2.6	5.6	8.8	12.7

grid. The electricity load of Taktse was 2.6 MW in 2005. Assuming the annul population growth rate is 1.2‰ and the electricity consumption per capita growth rate is 10%, the electricity load in future years are forecasted in Table 5.

TAR is famous for its high potential of hydropower energy, especially the small hydropower plant (SHP) provided essential energy for living in many remote and off-grid villages and towns. Now there are 56 county level rural hydropower stations, 166 village level stations, which are still in operation, with total installation capacity of 89,896 kW. There used to be some small hydropower station in Taktse too, but until the end of 2005 there is only one hydropower station called Pingcuo still in operation. It is also collected to the central electricity grid.

After the first and second Rural Power Network Project in Taktse, only a few villages and households are un-electrified. The electrified proportion is 100%, 95.24% and 84.38% in town, village and household level, respectively, which is much higher than the average situation of Lhasa and TAR (Table 6). Except for one village called Zunmucai in Zhangduo town, which cannot access to electricity, most of the households in other villages are electrified. In total, there are 765 households and 4393 people with no access to electricity till the end of 2004.

3.1.4. *Fossil fuel*

Besides the main sources of above energies, there are also some fossil fuel used in rural households in Taktse, such as LPG and a small quantity of diesel oil and coal.

Parts of households in the agricultural area that are close to the main 301 national road connecting Lhasa and Taktse began to use LPG in recent years. Over 60% of the households had the gas stoves and ever used LPG. Even a gas station namely Hufeng was

Table 6
Electrified situation of different level of Taktse comparing with Lhasa and TAR

Level	Region	Including SHP and PVS		Excluding SHP and PVS		Taktse
		TAR	Lhasa	TAR	Lhasa	
Town level	Total	683	57	683	57	6
	Electrified	485	56	135	48	6
	Proportion (%)	71	98.20	19.80	84.20	100
Village level	Total	5931	241	5931	241	21
	Electrified	2432	182	640	158	20
	Proportion (%)	41	75.52	10.80	65.60	95.24
Household level	Total	545,600	79,931	545,600	79,931	4896
	Electrified	325,400	69,393	170,048	33,889	4131
	Proportion (%)	59.64	86.82	31.17	83.18	84.38

SHP, small hydropower plant; PVS, photo voltaic station.

established in the county town in 2006. But LPG is still used not very often because the price is much higher than cattle dung and other traditional fuel, it is just prepared for harvest season or cold season when there is lack of energy in most of the households.

As the economy developed, more and more motive power machines such as walking-tractors and motorcycles began to be used in rural households in Taktse. So diesel oil and gasoline are also consumed by rural section. Even coal can also be seen in some households.

3.2. Energy consumption structure

There are 4545 agricultural households and 355 pastoral households and the population is 21,874 and 2433, respectively, in Taktse in 2005. Then cattle dung, firewood and crop residue can be calculated by the consumption amount per capita of surveying households, which are divided into agriculture households (AHs) and pastoral or half-agricultural and half-pastoral households (PHs), respectively.

In surveying towns, almost 90% of the households have electrical appliances such as lights, TVs, radios and butter–tea-churning machines, and over 50% of the households have agricultural machines such as walking-tractors and motorcycles. Statistics data show that the total electricity consumption is 1,309,649 kWh and the total diesel oil consumption was 1,174,298 l in 2005. Number of solar stoves and cans of LPG consumed per household are 1.3 and 1.57 $year^{-1}$, respectively. Per can of LPG weighs 15 kg and costs 60 yuan. Solar energy can be estimated as follows: the stove is used for an average 6 h each day and its power is 1 kW commonly, assuming there are 200 days when solar stove can be used in 1 year and the heat efficiency is about 60%, then transform the heat energy into standard coal energy whose efficiency is 15% and calorific value is 29,271 $kJ\,kg^{-1}$. All the results are shown in Table 7.

We can see from Table 7 that the total energy consumption in rural Taktse in 2005 was 18,174.49 tce in which cattle dung takes up over 55% and solar energy and firewood are another two main kinds of energy sources in rural section (Fig. 2).

Table 7
Rural domestic energy consumption appraisal in Taktse in 2005

Energy type	Consumption per capita		Total amount	Coefficient	Total energy (tce)	Proportion (%)
	AHs	PHs				
Cattle dung	800 kg	1640 kg	21,489 t	0.471	10,121.47	55.69
Firewood	120 kg	100 kg	2868 t	0.571	1637.73	9.01
Crop residue	70 kg	50 kg	1652.8 t	0.500	826.42	4.55
Electricity	1,309,649 kWh			0.1229	160.96	0.89
Diesel oil	1,174,298 l			1.4571	1437.30	7.91
LPG	1.57 can of LPG per household			1.7143	199.44	1.10
Solar energy	1.3 solar stove per household				3791.18	20.86
Total					18,174.49	100

AHs, agricultural households; PHs, pastoral or half-agricultural and half-pastoral households.

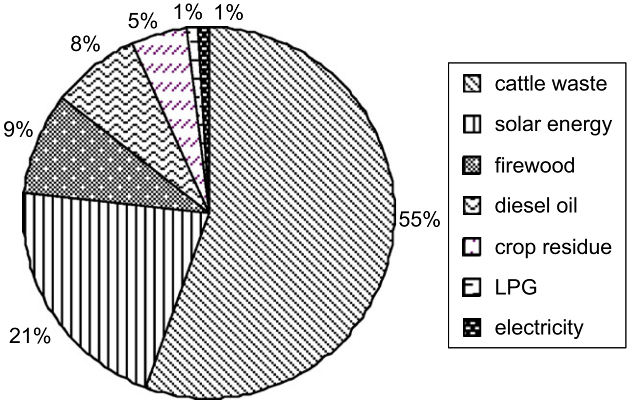


Fig. 2. Rural domestic energy consumption structure in Taktse in 2005.

4. Eco-environmental impacts of rural energy consumption in Taktse

Biomass takes up to almost 70% in the total rural energy consumption in Taktse in 2005. Local people collect dung, firewood and crop residues from agriculture sector and gain necessary energy from them. But like in other developing countries [1,2], this process induces tremendous eco-environment degradation, such as deforestation, soil erosion and desertification and some other health impact and social impact, such as time occupation and less education (Fig. 3).

4.1. Eco-environment degradation

Due to its complex ecosystem inside a high and cold alpine region TAR belongs to the very fragile locations of China. The use of biomass is responsible for some environmental degradation in Taktse, too.

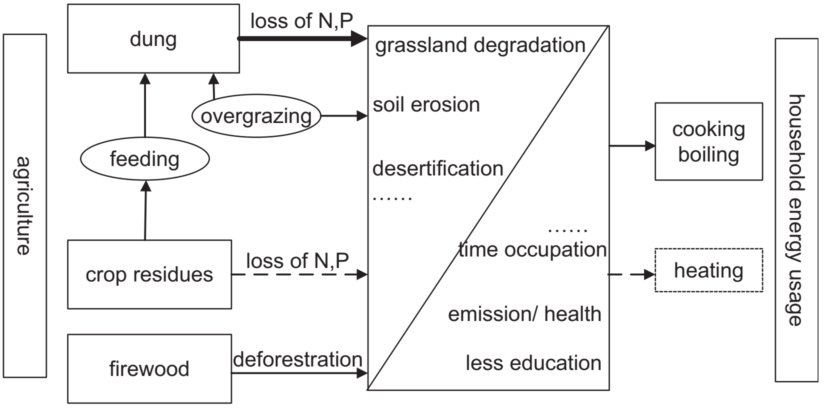


Fig. 3. Input–output flow of energy–environment in rural Tibet.

Table 8
Forest area (in ha) change in Taktse

Year	Area of forest in Taktse
1980	11,816
1995	3505
2000	12,240
2005	10,545

Table 9
Soil erosion (in km^2) in different towns in Taktse

Region	Land area	Tiny erosion				Developmental degrees of soil erosion			
		Area	%	Total	%	Slight	Middle	Serious	Extremely serious
River valley	148.36	42.7	28.8	66.26	44.7	57.36	0.81	2.9	5.19
Deqing	398.32	144.26	36.2	186.43	46.8	78.67	87.82	19.94	
Tajie	150.11	50.51	33.6	77.28	51.5	25.47	35.13	15.43	1.25
Zhangduo	124.83	29.54	23.7	83.66	67	24.74	45.43	13.28	0.21
Tangga	224.89	47.25	21	164.16	73	79.34	73.74	9.27	1.81
Xue	170.29	34.39	20.2	125.82	73.9	50.11	65.86	9.12	0.73
Bangdui	152.67	21.77	14.3	123.38	80.8	43.48	54.86	19.76	5.28
Total	1369.47	370.42	27	826.99	60.4	359.17	363.65	89.7	14.47

Deforestation, which is caused by firewood consumption and also led to soil erosion and desertification, used to be a very serious problem in Taktse (Tables 8 and 9). During the 60th, 70th and 80th of the past century, cutting-down and burning of firewood in the forest and shrubs along the river valley widely led to a sharp decline of forest (Fig. 4). The area went down from 11,816 ha in 1980 to the lowest level in middle 1990s, after which wood were restricted to be used as fuel and local government began some afforestation projects, then forest area went back above 100 km^2 again after 2000.

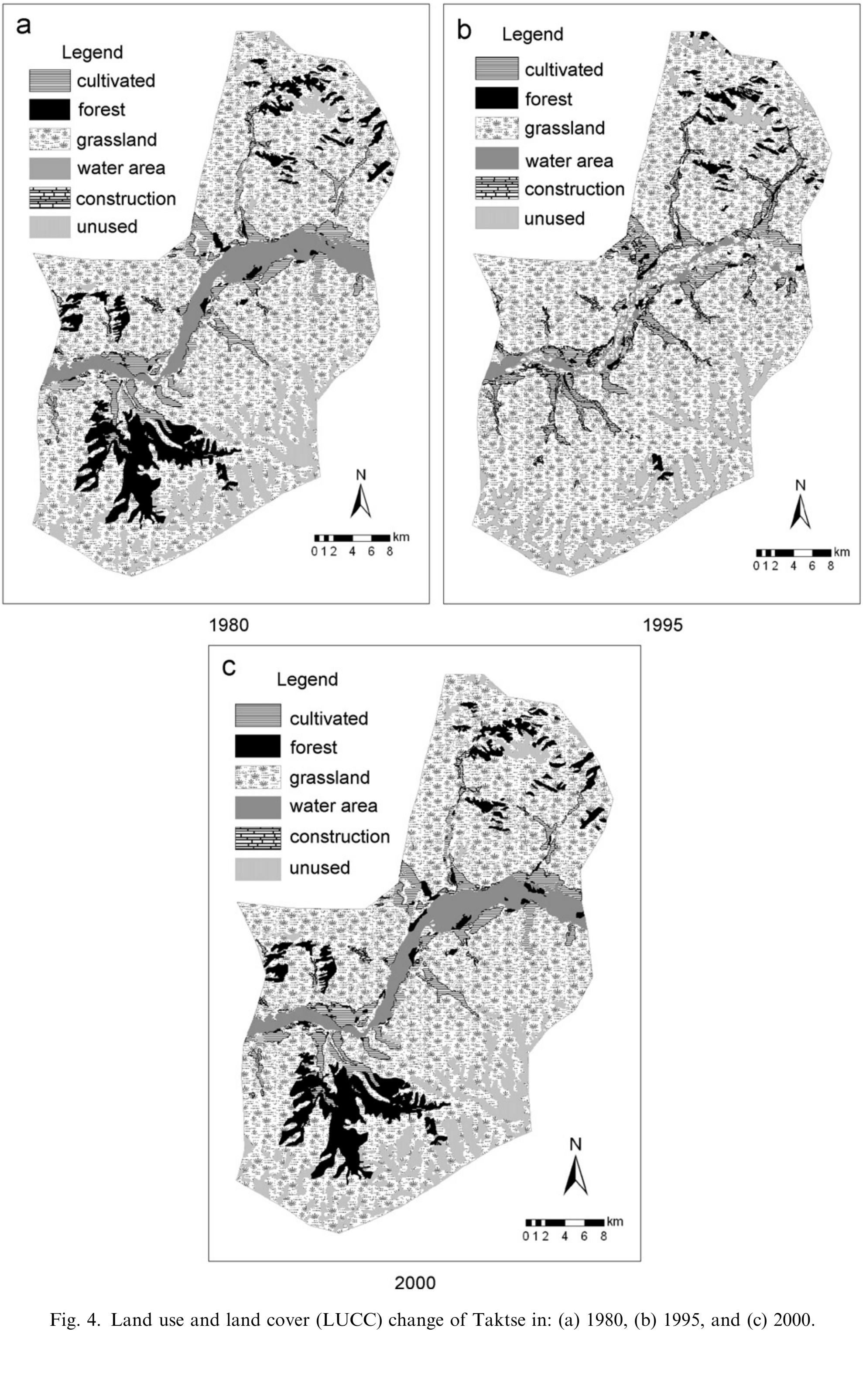


Fig. 4. Land use and land cover (LUCC) change of Taktse in: (a) 1980, (b) 1995, and (c) 2000.

Table 10
Grassland degradation (in ha) in different towns in Taktse

	1991	Proportion (%)	2000	Proportion (%)	Increasing rate (%)
Degradation area	40,160	36.1	55,206	51.2	36.9
Slight degree	21,693	54	25,151	45.5	15.9
Middle degree	11,814	29.4	19,664	35.6	66.5
Serious degree	6653	16	10,391	18.8	56.2

Table 11
Desertification situation in Taktse compared with Lhasa and TAR

Region	Serious degree	Middle degree	Slight degree	Potential	Total desertification area	Proportion in region area
TAR	1254.35	16,767.03	12,688.88	2047.77	32,758.94	18.17
Lhasa	14.19	75.44	165.95	22.83	278.43	6.41
Taktse	0.77	6.19	10.76	0.4	18.12	9

Cattle dung collection and consumption results in a decreased fertility of soils and is to some extend responsible for soil degradation which leads to grassland degradation and desertification, too. Crop residues in Taktse are mainly used for feeding up to 95% more than as fuel whereas a small account of crop residues is used for dung fertilizer being mixed with other organic materials. Therefore, the main potential organic fertilizer for grassland is cattle dung which is used for fuel to some extend, resulting into a growing gap between N and P output and input, leading to soil degradation [15]. This means a further consequent pressure on pasturelands, which is mainly evoked by overgrazing due to an increase in herding and livestock population. There were 21,489 t cattle dung used in Taktse in 2005, taking up 41.6% of the total production. This means a great loss of 303 t N and 368 t P, although the use of chemical fertilizer and organic manure is 1400 and 180,000 t in total, with an average of 0.31 and 40.41 t ha^{-1}, respectively, in 2005 in Taktse. The degradation area of grassland in Taktse grows from 40,160 ha in 1991 to 55,206 ha in 2000, with an increasing rate of 36.9% (Table 10), and the proportion of total desertification area in region land area is about 9%, higher than Lhasa (Table 11).

4.2. Health impact and social impact

The usage of biomass in Taktse does not only have impacts on the eco-environment but also on human beings health and educational level like in many other developing countries of the world [16,17].

According to the results of our investigation in Taktse, approximately 33% of the stoves are open stoves without chimney that are used inside very often also during summertime in order to burn biomass for cooking and boiling water. In this range high concentrations of CO, NO_2, SO_2 and TSP are released within a few years [18], which can led to chronic diseases such as pneumonia and even lung cancer, allergies and skin and eyes diseases. Women and children are concerned much more often because they get much closer to the stoves and fire locations.

Table 12
Time occupation of biomass energy collecting

	Main participator	Period of time	Time occupation per year (h)
Cattle dung	Women, elders, children	All year, 1 h per day	365
Firewood	Man	December	30
Crop residue	Woman, children	October	40

Based on the interviews with the households and filling answers of the questionnaires, the average time that biomass energy were used is about 4 h per day, especially in the morning and in the evening for food and warm, and maybe a little longer in winter, and 88% of the people stated there is heavy smoke, of which 96% suffer from one or more diseases resulting from high CO, CO_2 and SO_2 inside their rooms. Even though we have not been able to get reliable information from the local hospitals, we see the description of the rural people as a clear indicator of health problems resulting from the usage of biomass inside rooms using open fires.

A further problem that is caused by the usage of biomass is the time that is needed to collect it. The average time that is needed to collect cattle dung inside grazing and farming regions is 1 h per day (Table 12). Every morning, the first task for women is collecting dung in the livestock corrals. This is a time loss for productivity, recreation and education (e.g. reading and learning). Very often the time after the collection of biomass cannot be used for education either because people are too tired. Adding the time that is needed to prepare cooking and the process of cooking itself we estimate a daily average time of nearly 6 h that is spent on the consumption of biomass in Taktse.

4.3. Driving forces

Besides the natural and socio-economic situation, which decides the energy supply potential in Taktse, there are also some other important driving forces of the relationship between rural energy and eco-environment.

(1) *Cultural tradition*: Cultural tradition, which is affected also by natural situation and socio-economic backgrounds, is a very important factor in the relationship between rural energy consumption and eco-environment in TAR. The traditional lifestyle of local Tibetan lead to their special energy consumption structure and behaviors. Livestock does not just means money or meat but a series of eating, warming, clothing, transportation and also energy sources to the local Tibetan. We can see the food structure, which is decided by cultural tradition and has close relationship with energy and economy parameters as an example in Table 13.

(2) *Population growth*: Overgrazing is a main reason for the grassland degradation and population growth plays a great role in overgrazing. In Fig. 5, we can see the growth of rural population and heads of livestock calculated by sheep units from 1959 to 2005. As we discussed above, local people in Taktse use milk, meat, butter, and wool from their animals and exchange some surplus for grain and daily necessities. The population needs a certain amount of livestock to meet their basic consumption. Fig. 5 shows that sheep units per capita keep around 13 for 47 years. The main factor

Table 13
Food consumption structure change in Taktse of 1996 and 2005

	Tsampa	Wheat	Rice	Highland barley wine	Tibet butter tea	Meat	Cheese	Vegetable	Other
1996	30.8	22.8	7.5	6.8	7.7	7.8	6.9	3.6	6.1
2005	19.4	29.6	16.0	10.5	3.3	4.1	4.1	13.1	0

Tsampa: a traditional Tibetan food, roasted barley with butter and cheese. Data source: data in 1996: Ref. [19] and data in 2005: our survey in Taktse in June 2006.

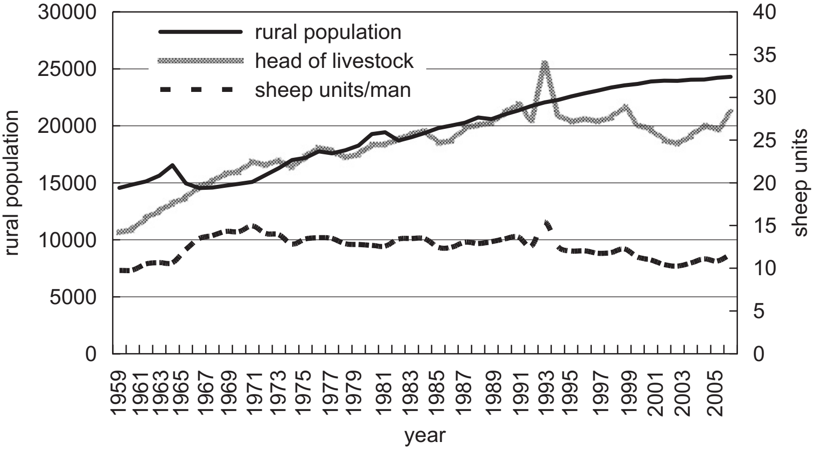


Fig. 5. Change curve of rural population and livestock in Taktse from 1959 to 2005.

for overgrazing is population growth. Some other research also proved this. Long-time observation in Damxung [20], which is located in the north of Lhasa and is a pastoral county, shows that this constant amount is about 20 sheep units per capita from 1952 to 1984.

(3) *Economy reason*: Besides the population growth, economy demand also becomes a reason for overgrazing and energy consumption increase gradually. The demand for better life causes the livestock increase and change of energy consumption structure. Change of food structure in Table 13 shows that the ratio of traditional food such as tsampa, Tibet butter tea, meat and cheese decline very clearly, while the ratio of wheat, rice, wine and vegetable increase markedly in the past 10 years. It is a reason of and also benefits from agricultural structure change induced by economic reasons. In addition, quantity of total vehicles including tractors and motorcycles in Taktse increases from 34 in 1981 to 1347 in 1996, and 3669 in 2005. We can also see in Table 14 the increasing trends of rural electricity consumption and agricultural motive power as time goes on and economy develops.

(4) *Policy guidance*: Good and suitable policies can relieve the eco-environment problems induced by energy consumption. Due to the fragile ecology and great potential of renewable energies in TAR, the local and central government have been trying to popularize modern and clean renewable energies, such as solar, wind and hydropower energies for many years. Another very good example is the use of firewood, the forest

Table 14
Energy consumption change as economy develops from 1997 to 2005

	Units	1997	1998	1999	2000	2001	2002	2003	2004	2005
Quantity of vehicles		1495	1559	1766	1820	2305	3124	3244	3545	3669
Rural electricity consumption	10^4 kWh	1.02	3.05	14.6	21.9	30.8	36.95	58.1	99.8	130.96
Agricultural motive power	10^4 kW	1.55	1.67	2	2.4	2.5	2.7	4.6	4.6	3.4

area increase a bit after the logging ban induced by local government in 1998 and China's Western Development Program and Grain for Green Campaign in 2000 which aims at converting cultivated land back to forest or grassland.

5. Discussions and suggestions

According to our investigation, we can give some general suggestions how to reduce the emission of green house gases as well as health aberrations. We suggest a multilevel policy making less use of traditional biomass and invest more resources in solar energy, biogas and electricity.

5.1. *Improve stove efficiency*

When using biomass, over 30% of the Tibet rural households, as was seen in our survey, use cattle dung for boiling and cooking either on traditional three stone stove or semi-enclosed mud stove without chimneys whose efficiency is not more than 15% with a further parameter of less oxygen in the air. In our indoor experiment in Taktse, traditional stove, about 35 cm in diameter, needs 30–40 min to boil a pot of water, while new energy-saving iron stove, about 20 cm in diameter, needs only 15–20 min to boil a pot of water. Most of the people stated a high willingness to invest more of their income in more efficient stoves whose efficiency is about 60–80% and only cost 320 yuan. For the short-term improving the stove efficiency can be one step in order to reduce emissions of greenhouse gases and avoid indoor pollution [21].

5.2. *Widespread use of solar energy and LPG*

In both the agricultural and pastoral areas, the use of solar stoves plays very important role in the range of boiling and lighting during the day. Solar energy in both areas is abundant and does not have any impact on eco- and socio-economic environment [22]. Therefore, we see solar energy as a sustainable solution for boiling and lighting during daytime. Improving the income situation of the households and being able to offer solar panels that can also store energy people will be able to use solar energy during the evening, too. The installation of solar-heated rooms inside both areas should be another measurement. In a long-term run solar thermal power unit must be taken into consideration, too. Especially in the pastoral area, where people depend on solar energy due to a lack of electricity policies have to be made on tapping the full potential of solar energy. Of course, this mainly depends on the ability to finance and to maintenance the plants. Another suggestion is that to train some local technicians with the management and

maintenance of the solar equipments, especially for PV equipments, because it was usually seen that nobody can repair it when it did not work only after 1–2 years.

As we could state, the use of LPG for boiling and cooking has been getting more and more popular especially in agricultural areas. Regarding the volatility of prices of LPG and the increasing shortage of LPG within the following years, the use of LPG can only be seen as a middle term solution.

5.3. Great potential of household biogas plant

There are also great potential to develop household biogas plant in Taktse. In general, the usage of biogas is seen to be the most efficient and environment-friendly way inside rural areas to reduce great amount of greenhouse gases emitted by the usage of traditional biomass like the direct burning of solid biomass [23]. In many other rural regions of China, biogas in terms of small single units of biogas plants per household is used successfully for many years helping to reduce greenhouse gases [24].

For an economic use of biogas plants, the climate of a region plays a key role. As Nepal, as a neighboring country, shows successfully the installation of biogas plants helped to reduce the use of traditional biomass enormously during the past 30 years, it proves no problem in Lhasa and the southern parts of TAR to build biogas plant after some experiments. The high solar radiation in Taktse could be used to broil organic material in terms of animal, plants and human waste, and there are also 14.4 t waste water and 6000 m^2 municipal waste in the small 1.66 km^2 county town in 2005.

From the second half year of 2006, the government began a program to develop 8000 household biogas plants in eight counties in TAR including Taktse. Till the end of 2006, 630 household biogas plants have been built in which 82 plants were built in three towns in Taktse namely Deqing, Bangdui and Tajie. Under beneficial conditions, the waste of livestock could produce 3–4 m^3 methane inside a biogas plant, which would deliver energy for approximately 6 h for cooking, lighting or heating. In a long-term run, biogas can help to substitute LPG for cooking, boiling and lighting and in addition could be even used to generate electrical power.

5.4. Adjustment of agriculture structure

Agriculture structure is very important both for rural economy development and for rural energy and environment development. As discussed above, the ratio of crop residues to feed and burn and fuel–fodder–fertilizer relationship are key problems between energy and environment in rural Tibet [25]. In order to guard rural household energy security and environment cleanness, government should make some countermeasures to adjust agriculture structure and improve rural economy.

In fact there are two parameters that aggravate a fast improvement of the energy situation in Taktse. One important parameter is the socio-economic site in terms of traditions combined with a lack of consciousness of impacts and feedbacks with regard to eco-environment. The implementation of most suggested energy technologies have relatively high initial costs and in addition the long-term financing due to managing and maintenance must be assured. This makes the competition with the use of traditional energy sources very difficult, especially with regard to solar energy and biogas. Besides financial support from the government energy related services must be establish in Taktse

to initiate a stronger economy that can help to improve the income situation of households. Due to the low population density, especially inside the pastoral area, it will not be possible to connect all households to a power grid. Therefore, a local organization of energy supply imbedding a energy-mix of solar energy and biogas is the most efficient way in a long-term run being able to balance costs and benefits of energy technologies in Taktse.

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